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DESIGN AND FABRICATION OF HYDRAZINE STORABILITY TEST TANKS

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Final Report

Arthur W. O'Brien, Martin Marietta Corporation
Charles L. Caudill, Martin Marietta Corporation

TECHNICAL REPORT AFRPL-TR-69-112

1969 June

Air Force Rocket Propulsion Laboratory
Directorate of Laboratories
Air Force Systems Command
Edwards Air Force Base, California

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Design and Fabrication of Hydrazine
Storability Test Tanks
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FOREWORD

This report was prepared by the Denver Division of Martin Marietta Corporation, under U. S. Air Force Contract F04611-68-C-0080. This contract was initiated under Purchase Request No. 30588512, Project Number 3058. The Martin Marietta report number is MCR-69-145. The contract was administered by the Air Force Rocket Propulsion Laboratory, Edwards Air Force Base, California. The program monitors were Major Roscoe Tanner and Lieutenant Richard B. Mears.

This report covers work performed under this contract from 1968 March 07 through 1969 March 10.

The program was performed at the Martin Marietta Corporation under the direction of Mr. Arthur W. O'Brien, Program Manager and Mr. Charles L. Caudill, Technical Director.

This technical report has been reviewed and is approved.

UNCLASSIFIED ABSTRACT

This report summarizes the work performed in designing, fabricating, and testing small-scale storable propellant tanks. The design incorporates full-scale missile tank features and typical weld stresses. Fabrication and test procedures are based on simulated production tooling and on actual procedures used in the manufacture of production tankage. The tank designs are based on seven different alloys. Five tanks were produced from each alloy. The alloys were: 2014-T6 aluminum alloy; 2021-T6 aluminum alloy; 2219-T6 aluminum alloy; 17-7 PH corrosion-resistant steel; A-286 corrosion-resistant steel; AM-350 corrosion-resistant steel; and 6Aℓ-4V titanium alloy. The tanks will be filled with N_2H_4 at the Rocket Propulsion Laboratory and stored in the RPl Storability Test facility. Tanks will not require passivation at RPL since they have been given a special accelerated hydrazine storability test at Martin Marietta. This process includes passivation.

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SECTION I

INTRODUCTION

In the past, the design of storable liquid-propellant tanks has been predicated on material compatibility data derived from simple specimens immersed in propellants. This type of data is necessary to record corrosion rates and resultant material strength after propellant exposure. However, specimen data cannot confirm the storable life of fabricated tankage that has undergone changes in metallurgical structure and residual stresses due to processing. Moreover, it is extremely difficult to duplicate, in specimen tests, the stress conditions that can exist at various joints in a pressurized welded vessel. Finally, the development of leaks, or propellant catalytic decomposition and resultant pressure rises as a function of exposure condition can only be determined when closed containers are evaluated.

It has therefore become necessary to demonstrate the long-term compatibility of fabricated tankage with various propellants. The current contract was initiated to provide tanks for an In-House Liquid Propellant Storability Program being conducted by the Air Force Rocket Propulsion Laboratory. These tanks will be placed in an environment of 100°F to 160°F and ambient relative humidity for periods of at least 5 years.

SECTION II

DESIGN

The hydrazine storage tanks, as designed under this contract, simulate actual aerospace vehicle propellant tanks. Materials, and fabrication and inspection techniques and processes are representative of normal aerospace application. In compliance with normal propellant tank design, ports have been designed into the tanks for pressurization, venting, fill, and drain. In all respects, the design goals of this contract have been to provide the best possible concept to satisfy the objectives of the AFRPL storability test program.

1. CRITERIA

The criteria established for this program were to design five hydrazine-compatible propellant tanks of seven selected metallic materials. The proposed design configuration that was accepted, with certain modifications, was similar to the configuration provided to AFRPL* under Contract AF04(611)-10794. Tank volume was established at approximately 10 gallons and tank operating pressure at 100 psig. Tank thickness requirements were based on 100 psia pressure with a safety factor of 1.5 on tension yield. Ports are provided on the tank ends for pressurization, venting, fill, drain, and propellant sampling. A removable cover with a mechanical seal was built into one end of each tank to provide access for X-ray weld inspection, internal weld-zone processing, and internal tooling removal. Tank supports were not required.

2. MATERIALS

Material selection was primarily based on propellant compatibility, weldability, and formability data obtained from previous small tankage contracts. Tank materials proposed and approved for this contract are listed in Table I.

*Hardware produced under Contract AF04(611)-10794 was delivered in 1965.

Table I Approved Tank Materials

Material	As-welded tensile yield strength (psi)	Tension yield allowable (psi)
X2021 aluminum	36,000	24,000
2219-T62 aluminum	18,000	12,000
2014-T62 aluminum	18,000	12,000
6Aℓ-4V titanium	120,000	80,000
A-286 stainless steel	40,000	26,700
AM-350 stainless steel	75,000	50,000
17-7PH stainless steel	80,000	53,300

A brief technical discussion on the performance and characteristics of the selected materials is present in this subsection.

a. X-2021 Aluminum Alloy. In applications requiring high strength-to-weight ratios, high ductility, low temperature notch insensitivity, and good compatibility, various aluminum alloys, such as 2014 and 2219, have been used in aerospace vehicle systems such as Saturn I, Saturn V, and the Titan vehicles.

Since increases in efficiency, range, and payload capability of vehicle systems will require higher strength materials, an extensive alloy development program was performed by Alcoa to develop materials with $F_{tu} \approx 75$ ksi, $F_{ty} \approx 65$ ksi, and an elongation of 15% with increased weldability (weld efficiency of 60%).

Aluminum alloy X-2021 (Tables II and III) (Aℓ-Cu type) was prepared by adding Zr, Cd, Ti, Sn, and V to 2219 aluminum alloy. The alloy is a complex composition requiring close control over 11 elements. Basic hardening is provided by precipitation of the Aℓ-Cu phase, with nucleation assisted by the presence of Cd and Sn. Manganese provides supplementary strengthening and aids in control of grain size. Ti is an ingot grain refiner and, together with Zr and V, minimizes weld cracking. An upper limit is placed on Mg content to avoid the formation of insoluble Mg_2Sn phase, which interferes with precipitate nucleation.

This alloy must be pre-aged at an elevated temperature before stretcher leveling to aid precipitate nucleation and strength development.

Table II Metallurgy of X-2021 Aluminum Alloy

Chemical composition	
Element	Limits
Si	0.20
Fe	0.30
Cu	5.8 to 6.8
Mn	0.20 to 0.40
Mg	0.02
Zn	0.10
Ti	0.02 to 0.10
Zr	0.10 to 0.25
V	0.05 to 0.15
Cd	0.05 to 0.20
Sn	0.05 to 0.08
Others, each	0.05
Others, each	0.15
Aℓ	Remainder

Physical properties	
Density (lb/cu in.)	0.103
Melting point	997 to 1195
Electrical conductivity at 20°C	(% relative to copper)
0 temper	44
WE5 temper	30
T81 temper	32
T62 temper	31
Thermal Conductivity at 25°C, metric units	
0 temper	0.41
T81 temper	0.30
Average coefficient of thermal expansion for T81 (in./in./°F)	
68 to 212°F	12.6
68 to 302°F	12.9

Table III Design Properties for X-2021-T81 Sheet and Plate

Thickness (in.)		0.040 to 0.249	0.250 to 0.499	0.500 to 1.000	1.001 to 2.000
F_{tu} (ksi)	L*	66	66	66	65
	T†	67	67	67	65
F_{ty} (ksi)	L	58	58	58	56
	T	57	57	57	55
F_{cy} (ksi)	L	58	58	58	56
	T	60	60	60	58
F_{su} (ksi)		39	39	39	38
F_{bru} (ksi)	e/D - 1.5	102	102	100	97
	e/D - 2.0	131	131	129	126
F_{bry} (ksi)	e/D - 1.5	86	86	85	83
	e/D - 2.0	102	102	101	98
e, in 2 in. (%)		6	5	3	3

*L = longitudinal.
†T = transverse.

Weld properties for X-2021-T81 aluminum alloy

Postweld aging cycle	F_{tu} (ksi)	F_{ty} (ksi)*	Elongation in 10 in. (%)
Several weeks at 70°F	42	37	1.1
16 hours at 325 °F	46	46	0.7

*F_{ty}, 0.2% offset in 10 in.

Using 2319 aluminum alloy filler, X-2021 aluminum alloy is as readily welded as 2219 aluminum alloy. Postweld aging may be accomplished with an increase in yield and ultimate tensile strengths and a lower ductility. Welding parameters differ very little from those used in welding other weldable 2000-series alloys.

The Martin Marietta Corporation is presently testing 2021 aluminum alloy under Contract NAS3-11203, Cryogenic Alloy Screening. This work is being done to evaluate the flaw growth characteristics of 2021-T81 and 7007-T6E136 aluminum alloys and cryoformed 301 stainless steel.

b. A-286, AM-350, AM-355 Stainless Steels. A-286, AM-350, and AM-355 are age hardenable steels that combine high strengths at elevated temperatures with good corrosion resistance. They are compatible with the hydrazine base propellants, and are readily formable, weldable, and available in all forms. Their use in recent years has been widespread in the aerospace industry for bellows, feed lines, and fasteners. Martin Marietta Corporation has performed extensive compatibility testing on these materials. However, our use of these materials has been rather limited since their strength-to-weight ratio for ambient temperature applications is lower than many other structural materials, particularly aluminum and titanium alloys.

c. 6Aℓ-4V Titanium, 2014 and 2219 Aluminum Alloy, and 17-7PH Stainless Steel. Small-scale tanks of these materials in a similar configuration have been manufactured by Martin Marietta on Contract AF04(611)-10794. Material performance and characteristics were reported in that contract.* Application of this valuable information and experience has been projected into this contract with good success.

3. HYDRAZINE STORABILITY AND MATERIAL COMPATIBILITY

a. Hydrazine Fuels Storability Technology. Over the past decade Martin Marietta's Denver Division has conducted numerous investigations and evaluations of hydrazine and amine fuel mixture compatibility with tankage materials at ambient temperatures. More recently, as interest in effects of elevated temperature exposures has increased, additional tests have been run involving contemporary tankage materials with N_2H_4, MMH, MHF-5, UDMH, and other fuels. These evaluations, conducted on both contracted and company-sponsored programs have resulted in greatly improved understanding of the effects of time, temperature, and contaminants on the storability and end usefulness of these propellants. Information in this section includes data developed in testing at elevated temperatures. While this testing was not a requirement nor conducted on this program, it did form a part of technology that resulted in development of the passivation process discussed in Section IV, Acceptance Testing.

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*Report No. AFRPL-TR-65-194.

Hydrazine, other amine fuels, and their mixtures have a common property; they all are susceptible to decomposition both through catalytic and reduction reactions. Whenever stored in fuel-compatible containers and not exposed to extreme heat, the fuels are inherently stable. If the container is constructed of fuel compatible material, problems related to propellant decomposition are then those caused by one of the following:

1) Impurities, either dissolved or suspended, in the propellant;
2) Contamination residual in the system that may cause catalytic decomposition or reduction reactions;
3) Environmental temperatures that exceed those for which the materials of construction were originally tested for propellant compatibility.

The majority of the impurities or contaminants discussed in the first two items above have been identified. However, unpredicted or unexplained propellant decomposition has led to the initiation of several industry studies of the effects of these contaminants. One intent of these studies is to pinpoint those contaminants that contribute to decomposition so that realistic propellant procurement specifications can be established and propellant system cleanliness requirements can be appropriately defined. Process specifications used in fabrication of the tanks under this contract represent the most recent significant developments.

b. Materials Compatibility with N_2H_4 in Various Thermal Environments. Selection of construction materials must reflect propellant compatibility at the maximum temperature to which the system will be exposed. Reactivity of propellants with materials cannot necessarily be extrapolated over a large temperature spread. However, data gathered from tests conducted at temperatures above those planned can be useful. For example, the following paragraphs compare stainless steel with aluminum and titanium when exposed to hydrazine at 120°F and 275°F.

(1) N_2H_4 - Stainless Steel Compatibility at Ambient Temperatures. When stainless steels (Types 304 or 320) are chemically cleaned to remove all hydrocarbons, dirt, weld scale, and oxides and are then treated with a water solution of hydrazine for 24 hours, they exhibit good propellant compatibility.

When environmental temperature of a system will not exceed 120°F, tanks fabricated from these materials can be expected to contain N_2H_4 for extended periods without a significant amount of propellant decomposition.

(2) N_2H_4 - Stainless Steel Compatibility at 275°F. When the stainless steel alloys are cleaned, as described above, and exposed to hydrazine at 275°F, system pressure increases slowly beyond the normal vapor pressure. This pressure rise apparently continues indefinitely, indicating continuing decomposition, thereby eliminating these alloys for consideration for use with N_2H_4 at 275°F.

(3) N_2H_4 - Aluminum or Titanium Compatibility at Ambient Temperatures and 275°F. When aluminum or titanium alloys are cleaned to remove all contamination, they exhibit excellant compatibility with N_2H_4. A system constructed of these alloys would not need propellant passivation before final loading if it is assured that there is no residual catalytic or oxidizing contamination. Also, there is little difference between compatibility of hydrazine with these materials at 120°F or 275°F.

(4) Ease of Cleaning - Stainless Steel vs Aluminum or Titanium. Another important item of concern, when comparing the stainless steels with aluminum and titanium is that of ease of removal of oxides and the effect of oxide trace quantities remaining in the system. Stainless steel oxides are difficult to remove, especially from areas not accessible to mechanical cleaning. Also, trace quantities of these oxides seriously increase propellant decomposition. Removal of oxides from aluminum and titanium is no more difficult and, in some instances easier. Moreover, trace quantities residual in aluminum and titanium systems have no significant effect on rate of propellant decomposition.

As previously mentioned, test data acquired by testing materials for propellant compatibility at temperatures above those planned for operational use can be an important tool. The above discussion of stainless steel compared to titanium or aluminum results in the following conclusions:

1) Stainless steel would probably be suitable for long-term storage of hydrazine providing the system is clean and operational temperatures are below 120°F. It is possible however, that a pressure rise could slowly occur and in time exceed that allowable;

2) Titanium or aluminum alloys could be selected with a good deal more confidence. It is very unlikely that a properly cleaned system constructed of these materials, would generate sufficient pressure approaching that possible in a stainless steel stystem.

c. N_2H_4 Decomposition Following Elevated Temperature Exposure. As may be expected, the amine fuels, their mixtures with hydrazine, and water mixtures of either, are more resistant to decomposition than pure hydrazine.

One of the more significant observations made during recent compatibility tests of materials with hydrazine and monomethyl hydrazine at 275°F was related to the purity of residual propellant. After exposure of these propellants to a variety of metals and oxides that caused system pressures to reach 200 psig, gas chromatograph analysis was conducted. Purity of the propellants was, generally, found to be reduced less than 1%. The products of decomposition were vented atmosphere at the conclusion of the test, thereby causing contaminants to be removed and resulting in insignificant reduction in propellant purity.

4. CONFIGURATION

The tanks have been fabricated of the seven basic materials as previously specified. The completed tanks are shown in Figure 1 and are similar to the configuration provided to AFRPL under Contract AF04(611)-10794. Barrels are constructed of a roll-formed cylinder joined by a longitudinal weld. The tank closures consist of one-piece, ellipsoidal, explosively formed domes, with an access fitting and cover in one end and a combination fill, drain, and sampling port in the other. The fitting provides a coupling to pressurization, vent, and fill and drain systems. The access cover on one dome facilitates X-ray weld inspection, removal of internal tooling, and internal weld-zone processing. The mechanical seal was developed during the Titan II operational propellant storage program. This sealing method proved satisfactory in the small-scale storable-propellant tanks produced under our previous AFRPL contract. The tank dimensions result in a nominal volume of 10 gallons.

In conformance with the practice in previous storability program procurement, no tank supports have been provided. The tanks are designed so support loads are not critical; therefore, almost any support provided by Edwards Air Force Base will be satisfactory.

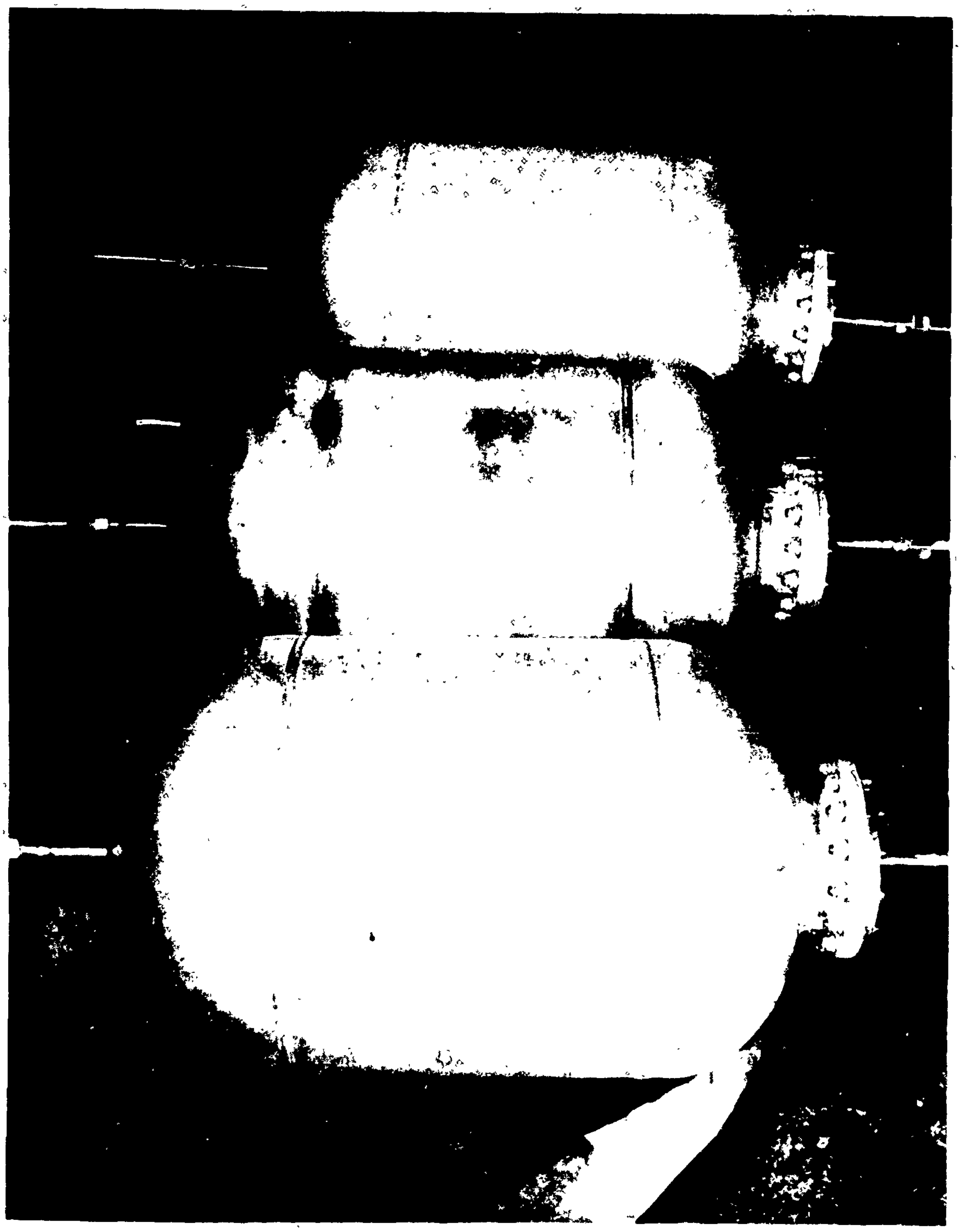

Figure 1 Final Configuration, Propellant Tank

AFRPL has developed a new design tube connector (MS 27851 and MS 27856) that is superior to connectors now being used in liquid rocket system applications. Since there is very little existing data on how these improved fittings will perform during long-term system storage, all 35 tanks under this contract have these connectors installed at each tank end.

5. DESIGN AND STRESS ANALYSIS

Table IV tabulates the calculated tank wall thicknesses, recommended thicknesses, actual stress, and actual factors of safety based on as-welded tension yield strength.

Table IV Tank Wall Thickness

Alloy	Required Thickness (in.)	Actual Thickness (in.)	Actual Stress (psi)	Factor of Safety
2014-T62 Aℓ	0.0495	0.071	8,380	2.15
2219-T62 Aℓ	0.0495	0.071	8,380	2.15
X2021 Aℓ	0.0242	0.065*	9,150	4.04
6Aℓ-4V Ti	0.0074	0.040	14,900	8.06
A286 SS	0.0223	0.040	14,900	2.68
AM350	0.0119	0.040	14,900	5.04
17-7 PH	0.011	0.040	14,900	5.36

*Minimum thickness for high-quality welding of aluminum is 0.060 in. This will be the thickness at the dome-to-dome cap juncture due to the thinout that occurs during explosive forming of the dome. Stresses will be highest at the dome/barrel juncture, where the thickness will be 0.065 in. for X-2021.

Table IV shows that the minimum required thicknesses are quite small, whether caluculated on the basis of yield or on known typical stresses. The gages are, for some materials, in fact, smaller than we believe to be feasible for quality production welding. Therefore, we have assumed material thicknesses based on the minimum required for high-quality welding.

Stress Calculations

$$^{*}S_H = \frac{ap}{t}\left[1 + 0.032\left(\frac{a}{b}\right)^2\right] = \frac{6.50(86)}{t}\left[1 + 0.032\left(\frac{6.50}{4.60}\right)^2\right]$$

$$S_H = \frac{559}{t}[1 + 0.064] = \frac{595}{t}\ ;\ t_{actual} = \frac{595}{S_H}$$

$$t_{reqd} = \frac{595}{S/1.5}$$

List of Symbols

S_H = actual hoop stress

S = stress (psi) (yield allowable for t_{reqd} calculations)

a = major semi-axis of ellipse (in.)

b = minor semi-axis of ellipse (in.)

p = working pressure (psi)

t = wall thickness (in.)

SF_{req} = safety factor = 1.5 on yield

2014-T6 and 2219-T6

$$(S/1.5)\ \text{Allowable} = \frac{18{,}000}{1.5} = 12{,}000\ \text{psi}$$

$$t_{req} = \frac{595}{12{,}000} = 0.0495\ \text{in.}$$

$$t_{actual} = 0.071\ \text{in.}$$

$$SF_{actual} = \frac{0.071}{0.0495} \times \frac{3}{2} \times 1.43 \times \frac{3}{2} = 2.15$$

$$\left(S_H\right)\ \text{Actual stress} = \frac{595}{0.071} = 8380\ \text{psi}$$

---

*Formula for discontinuity hoop stress from "Theory of Plates and Shells" Art. 116 by S. Timoshenko.

X2021

$$(S/1.5)\ \text{Allowable} = \frac{37,000}{1.5} = 24,600\ \text{psi}$$

$$t_{req} = \frac{595}{24,600} = 0.0242\ \text{in.}$$

$$t_{actual} = 0.065\ \text{in.}$$

$$SF_{actual} = \frac{0.065}{0.0242} \times 1.5 - 4.02$$

$$\left(S_H\right)\ \text{Actual stress} = \frac{595}{0.065} = 9150\ \text{psi}$$

6Aℓ-4V

$$(S/1.5)\ \text{Allowable} - \frac{120,000}{1.5} = 80,000\ \text{psi}$$

$$t_{req} = \frac{595}{80,000} = 0.0074\ \text{in.}$$

$$t_{actual} = 0.040\ \text{in.}$$

$$SF_{actual} = \frac{0.040}{0.0074} \times 1.5 = 8.1$$

$$\left(S_H\right)\ \text{Actual stress} = \frac{595}{0.040} = 14,900\ \text{psi}$$

A286

$$(S/1.5)\ \text{Allowable} = \frac{40,000}{1.5} = 26,700\ \text{psi}$$

$$t_{req} = \frac{595}{26,700} = 0.0223\ \text{in.}$$

$$t_{actual} = 0.040\ \text{in.}$$

$$SF_{actual} = \frac{0.040}{0.0223} \times 1.5 = 2.7$$

(S_H) Actual stress $= \frac{595}{0.040} = 14{,}900$ psi

<u>AM350</u>

$(S/1.5)$ Allowable $= \frac{75{,}000}{1.5} = 50{,}000$ psi

$t_{req} = \frac{595}{50{,}000} = 0.0119$ in.

$t_{actual} = 0.040$ in.

$SF_{actual} = \frac{0.040}{0.0119} \times 1.5 = 5.04$

(S_H) Actual stress $= \frac{595}{0.040} = 14{,}900$ psi

<u>17-7 PH</u>

$(S/1.5)$ Allowable $= \frac{80{,}000}{1.5} = 53{,}400$ psi

$t_{req} = \frac{595}{53{,}400} = 0.0111$ in.

$t_{actual} = 0.040$ in.

$SF_{actual} = \frac{0.040}{0.0111} \times 1.5 = 5.4$

(S_H) Actual stress $= \frac{595}{0.040} = 14{,}900$ psi

SECTION III

FABRICATION, TOOLING, AND FACILITIES

1. DOMES

Explosive forming was selected as the most efficient manufacturing method for one-piece dome fabrication. The process details and problems encountered and their solutions are discussed in this section.

a. Aluminum Alloys. The aluminum alloys presented the fewest problems in forming because aluminum is an ideal material to form with its high ductility, low yield strength, and its low strain rate sensitivity. The required thickness of the formed parts was close to ideal for forming. A D/t (die diameter to blank thickness) ratio of 150 approximately is considered to be ideal for explosively deep drawing most materials. The thickness of the three aluminum alloys ranged from 0.067 in. for the 2021-0 to 0.072 in. for the 2219-0 and 0.074 in. for the 2014-0. These thicknesses gave D/t ratios of 175 to 195. These values were well below the ratio of 300, which represents the minimum thickness for forming of most materials in deep drawing operations without encountering buckling in the finished part. The aluminum alloys' very high modulus of elasticity-to-yield strength ratio of approximately 1000 also reduces the buckling tendency of deep drawn parts.

b. Stainless Alloys. The stainless alloys were somewhat more difficult to form than the aluminum alloys because of two of the forming parameters mentioned previously. The three alloys ranged in thickness from 0.040 in. for the 17-7 PH and the A286 to 0.044 in. for the AM350. The resulting D/t ratios of 295 to 325 coupled with the lower modulus-to-yield strength ratios of 400 to 600 greatly accentuated the buckling tendency of the stainless alloys. It is apparent that the 0.040-in.-thick material represents a D/t ratio of over 300. This did indeed produce buckling in the domes; however, this problem was solved and the remedy is fully explained in subsection e, Forming. The excellent ductility of these alloys was very beneficial in correcting the problem.

c. Titanium. The 6Aℓ-4V titanium was the most difficult of the seven alloys to form. It has the worst modulus-to-yield ratio (115) of any of the alloys. However, the D/t ratio of 183 with the 0.071-in.-thick material was well within the formability range

of most materials. The very low modulus-to-yield strength ratio produced a severe buckling tendency in both the cavity and the flange area of the domes. The rather limited amount of ductility available in 6Aℓ-4V titanium in the annealed condition made the deep drawing operation on this material very difficult. This material also exhibits a very high notch sensitivity. This required surfaces and edges completely free of scratches and nicks.

d. Explosive Forming Die. The explosive forming die used to form these parts is shown in Figure 2. It consists of a mild steel die cavity having a 2:1 shape. A hardened 4340 steel shim ring 2 in. thick is bolted to the ellipsoidal die body to provide a 2-in. straight section and also a hardened draw radius to resist the wear and scratching that results from forming high strength materials. A 2-in.-thick clamping ring of hardened 4340 steel holds the blank in place on the die during forming. The die is equipped with an O-ring groove on the face of the die body and an O-ring groove on the upper surface of the shim ring to provide a vacuum tight seal between the die body, shim ring, and blank. This type of die was very satisfactory for forming all of the materials.

e. Forming. The aluminum alloys formed very readily with no flange or cavity buckling problems. The three alloys had small differences in yield strength and they also varied slightly in thickness. These variations were large enough, however, to change the explosive charge requirements for each alloy. All of the aluminum domes were formed in two shots. The first shot was tailored to form the dome to within 0.5 in. of the bottom of the die. A standoff distance (distance between the blank and the charge) was used, which produced maximum cupping and blank pull-in (Fig. 3). This in turn produced the least amount of thinout in the domes. The second shot required on each blank was essentially a sizing shot, and therefore much smaller because approximately 80% of the forming was accomplished by the first shot. A two-shot operation such as this produces a finished part with moderate thinout of the metal and a very close dimensional tolerance especially in the straight section of the dome. This ensured a minimum of mismatch between the dome and barrel section during welding. The only blank failures that occurred were the result of uneven pull-in or blank instability. This was corrected by using a slightly larger diameter blank.

Figure 2 13-in.-Diameter Dome and Explosve Forming Die

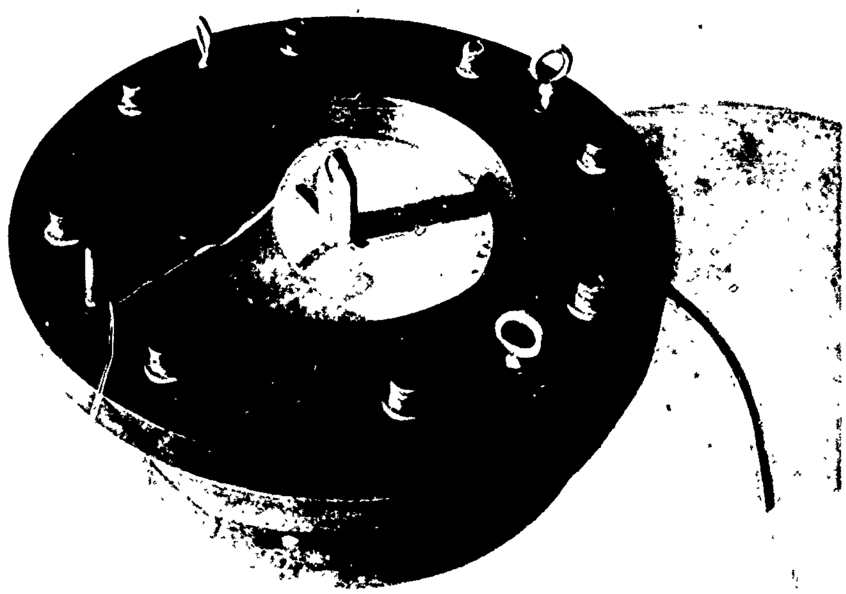

Figure 3 13-in.-Diameter Explosive Forming Die with a Part
Blank and Explosive Charge in Place

The stainless alloys were somewhat more difficult to form. The AM350 was the most difficult of the three to form, in that it showed the greatest tendency to buckle in both the flange and cavity areas. The three stainless alloys were all below the minimum thickness required to form deep drawn parts without buckling. The greater buckling tendency of the AM350 can probably be attributed to the fact that it has a higher yield strength in the annealed condition than either the A286 or the 17-7 PH. As previously stated, the high D/t ratios of the stainless alloys produced buckling in the cavity portion of the domes. The flange wrinkling was almost eliminated by using very high clamping pressures and lubricating the blanks to prevent excessive thinout or tearing of the domes. The blanks were formed to within 0.5 in. of the bottom of the die on the first shot (refer to Fig. 4), as were the aluminum domes. This shot produced some rather deep cavity buckles. The blanks were then removed from the die and completely cleaned of lubricant. They were then returned to the die and retorqued to an even higher level. When the sizing shot was made, the additional depth and filling of the part to the die contour was achieved almost entirely through stretching with very little flange pull-in. This stretched and flattened the buckles completely so that an acceptable part was produced. A certain amount of blank pull-in was necessary on the first shot at the expense of forming cavity buckles to prevent excessive thinout or breaking of the parts when formed to full contour. The higher yield strength of these materials produced a greater springback problem than was encountered with the aluminum alloys. This was satisfactorily reduced by adjusting the standoff of the charge on the sizing shots.

The 6Aℓ-4V titanium was the most difficult of any of the seven alloys to form. This material presents the worst possible combination of forming problems, namely low ductility, high notch sensitivity, and a very low modulus-to-yield strength ratio. The parts were very susceptable to cavity buckling after the first shot and these buckles were not easily eliminated because of the limited amount of elongation available in the material. A rather high percentage of blank failures (45%) was experienced in producing the required parts. A large percentage of these failures occurred because of compressive shearing in the flange area which then propagated a crack into the cavity. The flanges were very susceptable to wrinkling and the blanks were quite unstable on the first shot; that is, they showed a marked tendency to pull in unevenly for no apparent reason. This also caused premature failures. The blanks were not lubricated and high clamping pressures were used to prevent excessive flange pull-in. When the flanges were allowed to pull-in to achieve greater part depth, the flanges would then fail in compressive shear. The parts seldom failed because of tensile tearing at the dome apex.

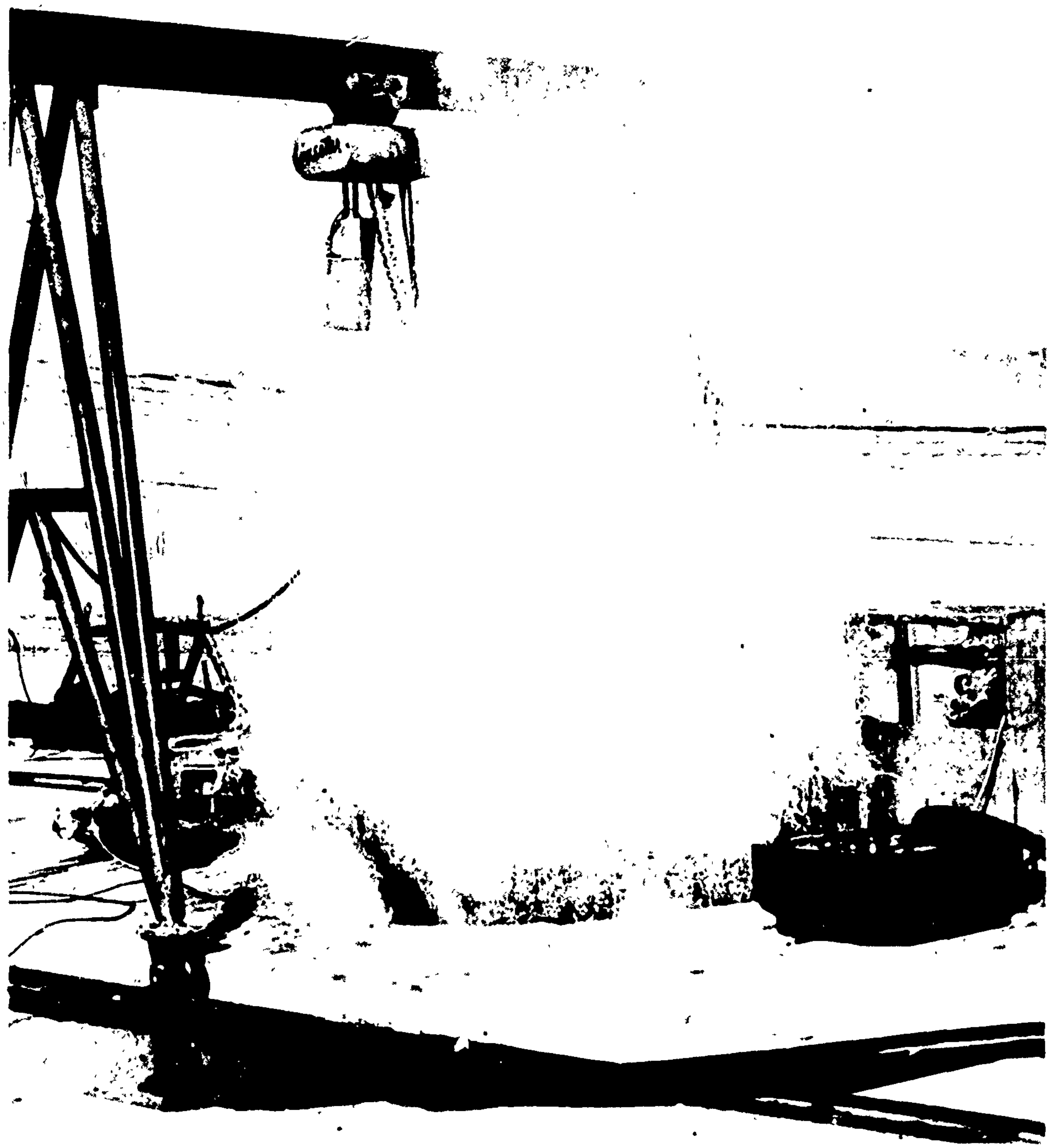

Figure 4 Explosive Forming of 13-in.-Diameter Dome Ends

The final process that produced parts with a minimum of compression buckling was as follows. The parts were formed in six shots using an intermediate stress relief between each shot. A full reanneal of the material would be extremely desirable; however, this is not feasible except at the mill. The parts were chemically cleaned and then stress relieved in an ABAR vacuum furnace to prevent any possible contamination that could cause surface embrittlement. Approximately 60% of the required depth was achieved on the first shot. It then took five shots and five stress reliefs to achieve the remaining 40% of depth.

2. WELDING AND TANK ASSEMBLY

The 35 tanks of seven different materials were fabricated using the following procedures. All processes and techniques used to fabricate these tanks were covered by the standard procedures that are being currently used at the Martin Marietta Corporation. Figures 5, 6 and 7 illustrate the completed tank, major sections, and mechanical cleaning prior to welding.

The as-received sheet stock was laid out into a pattern and identified in accordance with traceability requirements. These segments were then cut out and were either rolled into the barrel configuration or sent to the Ordnance Application Laboratory for explosive forming into a 13-in. dome.

The explosive formed domes were measured to insure that they were fully formed before the pilot hole was drilled in the apex of each dome (Fig. 8). The domes were then heat treated or aged as required. The forming flange was left on the steel and aluminum domes to help maintain the shape of the domes, but was removed from the titanium domes. The aluminum alloys were heat treated and aged after the domes were formed. The steel tank segments were aged after the forming operations. Prior to aging, a 1-in. undersize hole was cut into the 3-in. and 7-in. diameter fittings in the domes. The steel parts were coated with the Turco Pre-Treat before the aging operations. They were then cleaned after aging by vapor honing the surface. The titanium domes were aged in a vacuum furnace after the forming operations and before final trim operations.

The domes were then ready to be machined to the final apex hole size, which was either 3 in. or 7 in. (Fig. 9 and 10). This machining operation was performed with the flange still on the part to give the dome more rigidity in the machining operation.

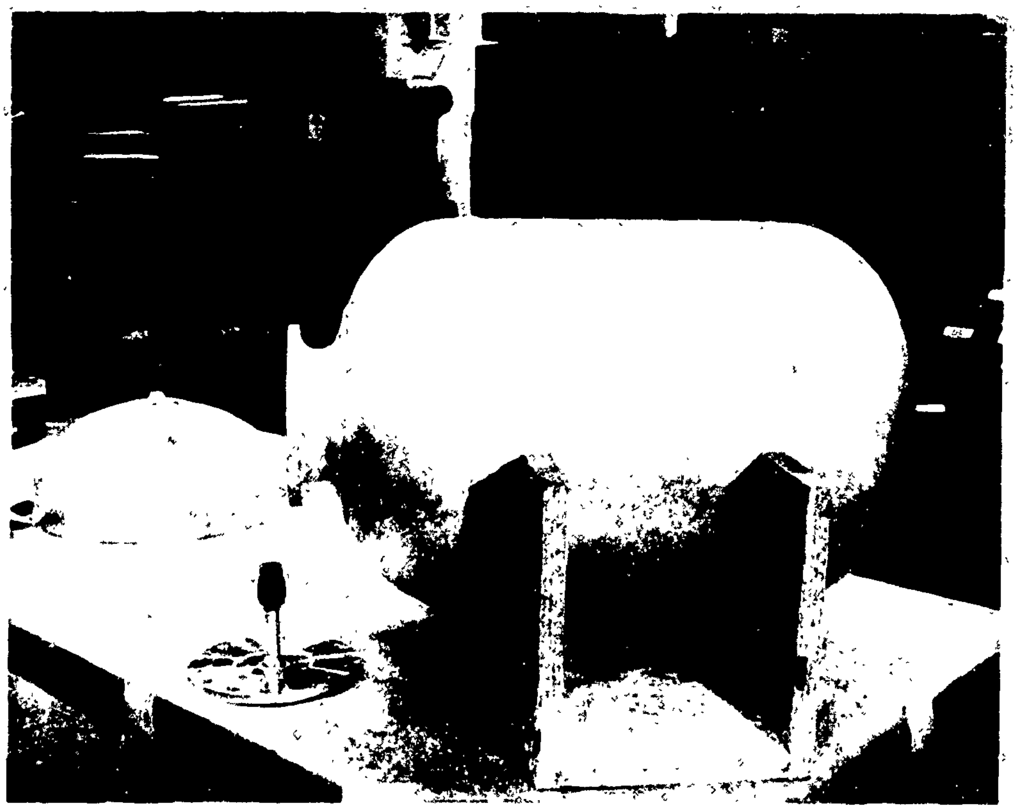

Figure 5 Completed 2219 Aluminum Alloy Tank and Access Cover Plate

Figure 6 Major Components of 2021 Aluminum Alloy Tank

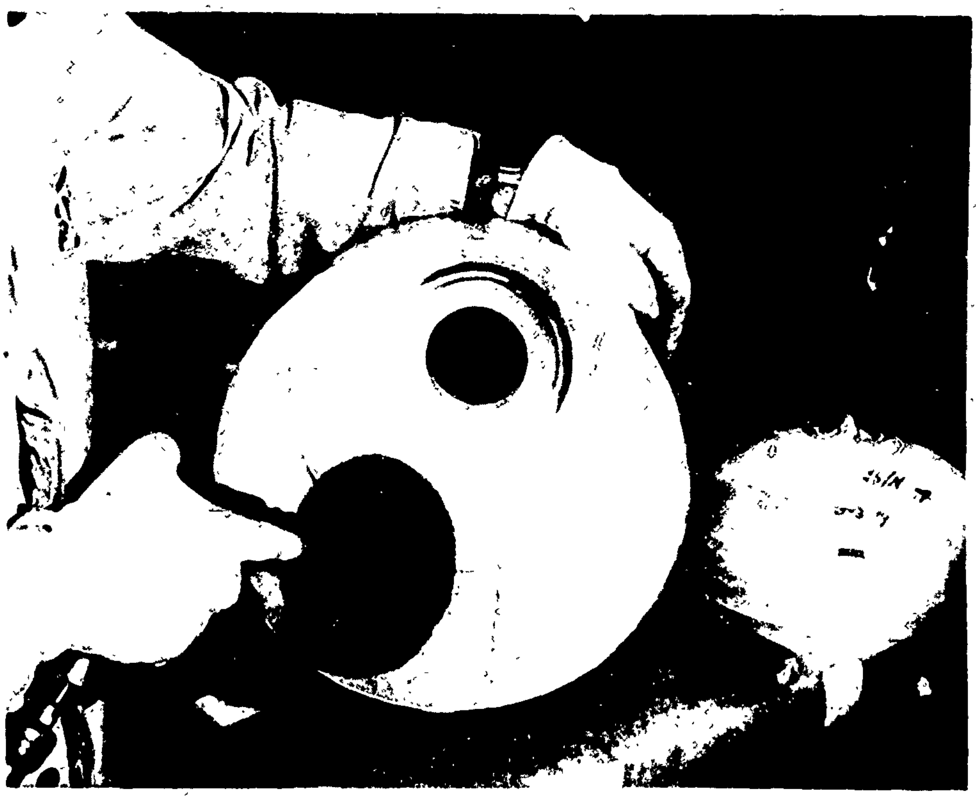

Figure 7 Mechanical Cleaning of 2219 Aluminum Alloy Tank before Making Final Weld

Figure 8 Checking Dome Diameter with Pie Tape

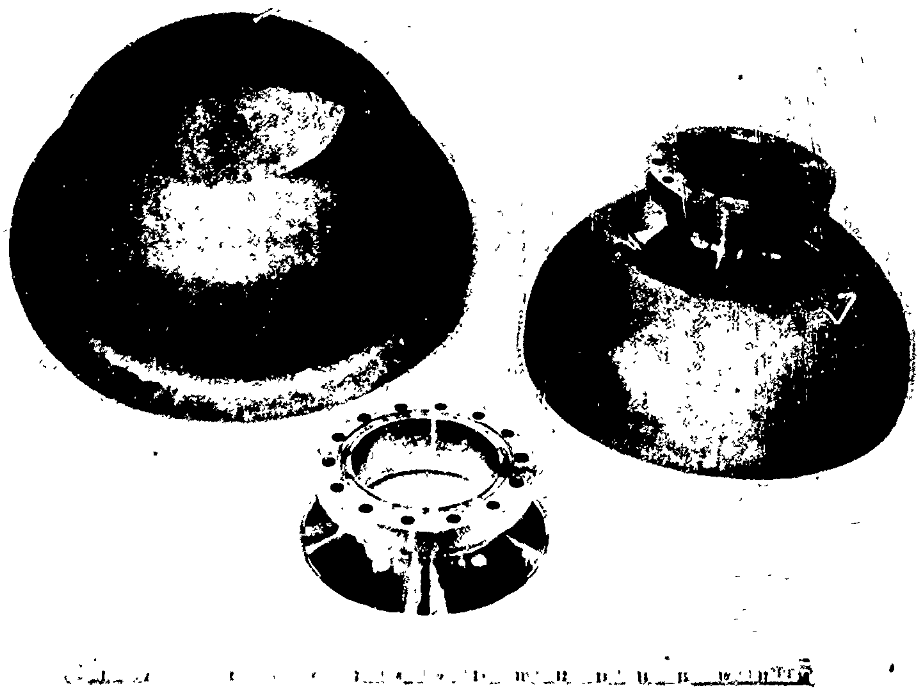

Figure 9 A-286 Alloy Domes and Access Port Fitting

Figure 10 A-286 Alloy Domes and Beanie

The 7 in.- and 3-in.-diameter outlets were then fitted into the domes. A shrink fit was used on all of the aluminum outlets. The outlets were cooled in dry ice and the dome was heated with a propane torch and then the parts were put together and allowed to form a shrink fit. The stainless steel and the titanium parts were machined to very close fits and were fitted into place without dry ice shrinkage.

The dome outlet welds were made by using an automatic welding setup with a rotary fixture that rotated the dome segment and outlet under the fixed torch position. The dome and outlet were both clamped securely to the fixture so that they could not move during the weld operation (Fig. 11, 12 and 13). This ensured a uniform weld on all the dome segments.

The welded dome assemblies were then ready to be trimmed to final size. The welded dome assemblies were placed on the trimming tool and trimmed to length. The exact diameter of each dome was measured using a pie tape after the final trimming operation. The domes were then matched as to diameters so that the barrel segment could be welded to an exact size.

Using the dome pie tape measurements the barrel segments were trimmed to a calculated dimension (Fig. 14). The barrel segment calculated dimension was set up to allow for weld shrinkage and taper if necessary so that each dome could be matched exactly.

The machined barrel segments were then welded (Fig. 15) so that their diameter met the requirements of the dome segments. After the barrel segments were welded they were trimmed to length on the barrel trimming tool so that the overall tank length requirement could be met.

All the parts were then ready for the final tank assembly fabrication procedures. The barrel segment and the 7 in. outlet dome assembly were set up on the barrel rotation fixture using an expandable mandrel to hold the barrel and dome in place. After the expansion mandrel was in position, the external ring holddown clamps were adjusted and placed adjacent to the weld zone on the barrel and dome assembly, respectively, for dome-barrel welding and tooling (Fig 16, 17 and 18). The barrel and the 7-in. outlet-dome assembly were welded using an automatic welding setup in the rotational fixture. After this initial circumferential weld was made, it was inspected and the setup was made for welding the 3-in. dome and outlet part to the other end of the barrel segment.

Figure 11 Fixture for Maintaining Dome Contour during End Fitting Installation (Welding head is not in position because hole for fitting has not yet been cut)

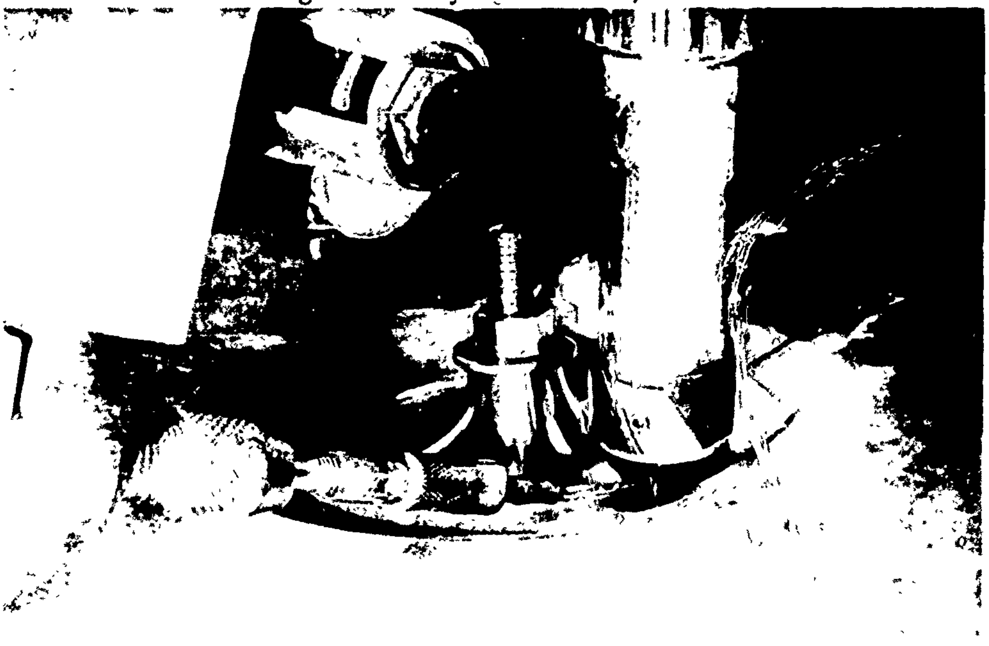

Figure 12 Welding Head and Wire Feed for Joining End Fitting to Dome (Surrounding flat plate holddown fixture is more clearly illustrated in Fig. 13)

Figure 13 Dome and Fitting in Weld Holddown Fixture after Welding

Figure 14 Tank Barrel Section in Lathe Fixture for Trim Machining

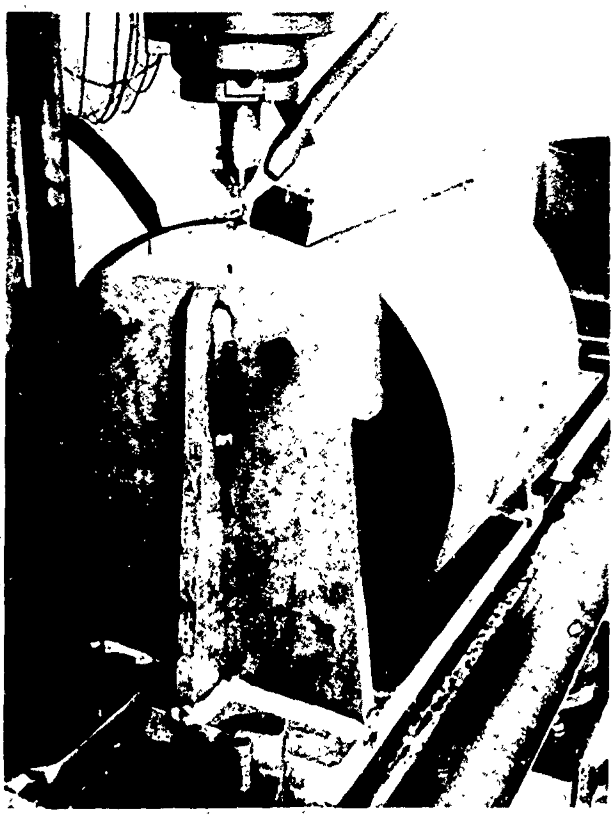

Figure 15 Barrel Section in Airline Welding Fixture for Longitudinal Weld

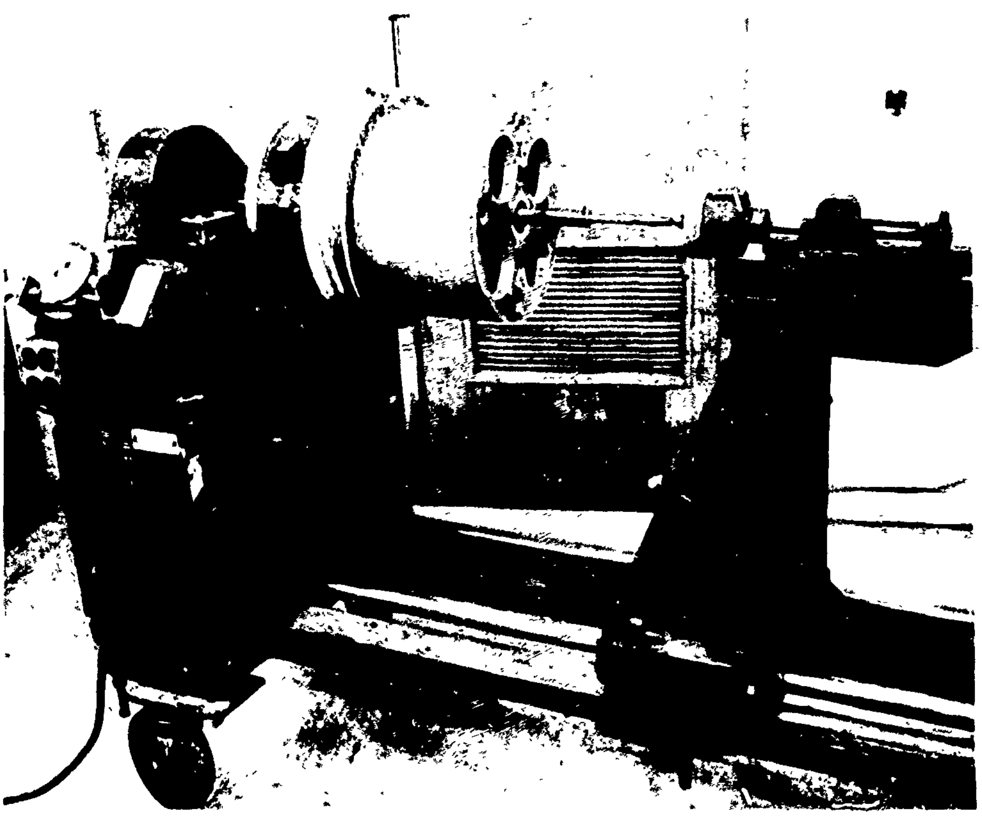

Figure 16 Dome-to-Barrel Girth Weld Fixture

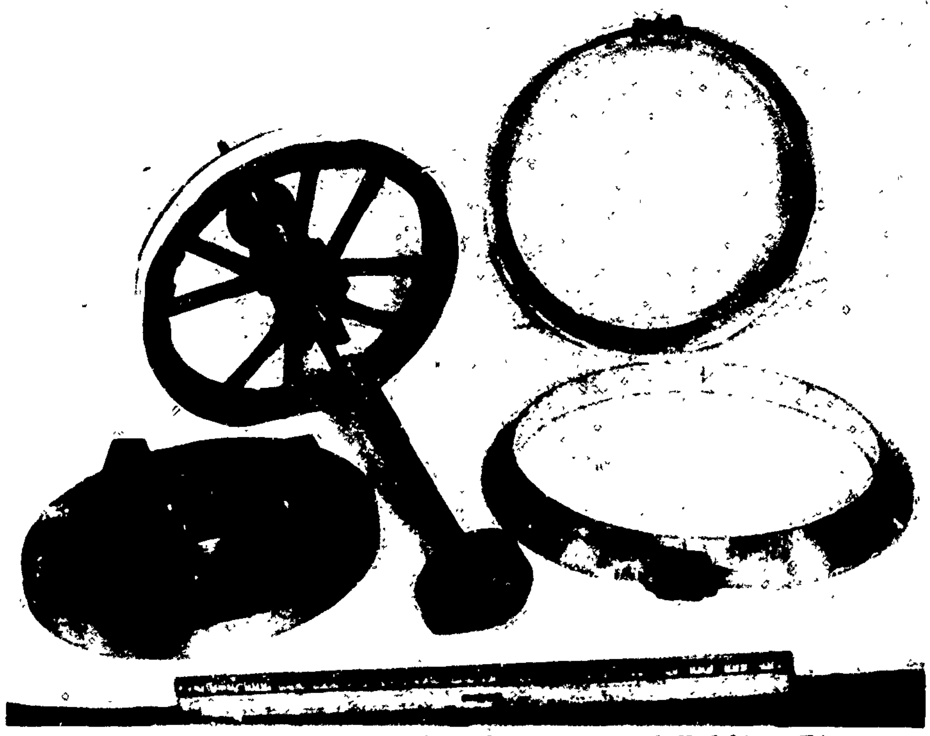

Figure 17 Expanding Mandrel and Associated Holding Fixtures for Performing Girth Weld

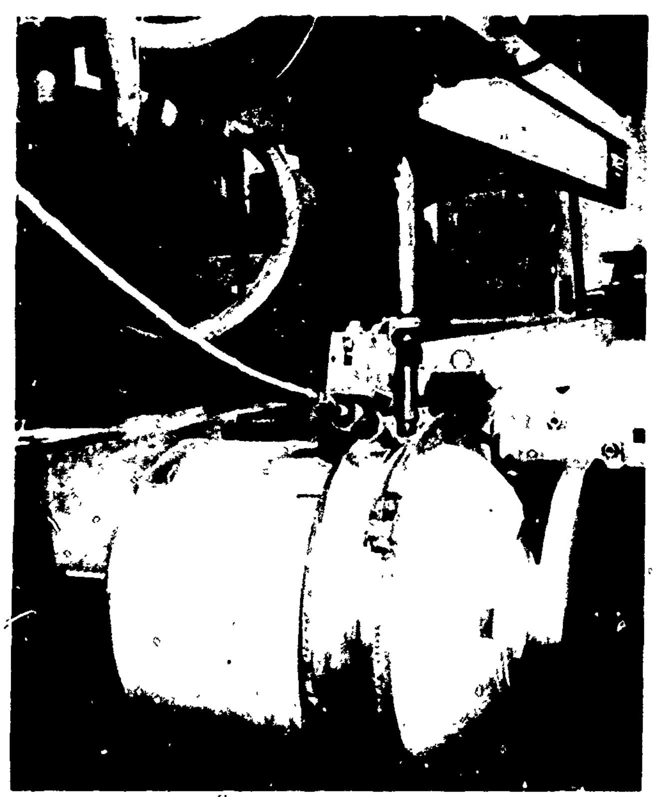

Figure 18 Welding Fixtures and Parts Ready for Dome-to-Barrel Weld, 2014 Aluminum Alloy

The expansion mandrel was placed into position for the dome-to-barrel segment weld. An inert gas coverage on the internal surface of the weld zone was provided for the steel and titanium welds. The external clamps were then placed into position and the final tank closure weld was made. The 3-in. outlet-dome assembly was then welded to the barrel segment. The internal expansion mandrel was collapsed and removed from the completed tank through the 7-in. outlet. The weld zone was inspected using dye penetrant inspection on all weld zones.

The outlet tubes were then welded to the 3-in. outlet fitting on the tank and to the cover plate for the tank. Manual welds were used to make this final closure in all cases. The tube assemblies were automatically welded on the steel and titanium parts (Fig. 19, 20, and 21). The aluminum tube assemblies were manually welded.

The tooling worked extremely well once it was set up and operational. It assured fast accurate welding setups with a minimal of delay for each weld. The expansion mandrel concept also worked well for making the barrel-to-dome closure welds. Fixtures for welding the two end fittings are shown in Figures 22 and 23.

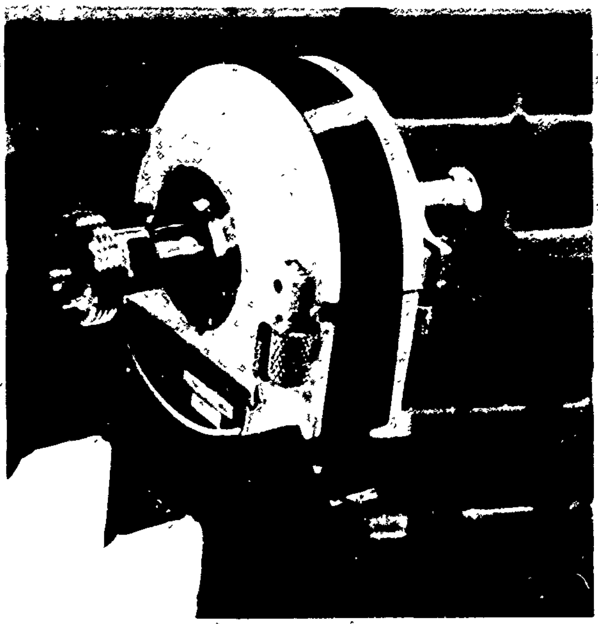

Figure 19 MS 27851 Connector and Tube in Automatic Tube Welder Head

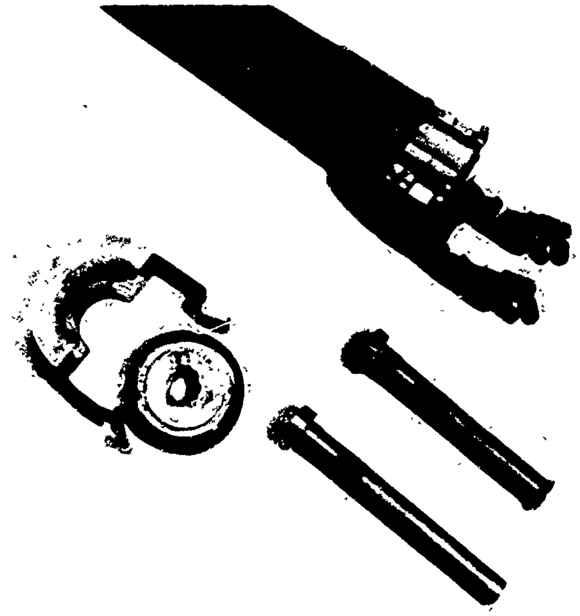

Figure 20 Disassembled Welding Head of Automatic Tube Welder and Welded Tubes with MS 27851 Connectors

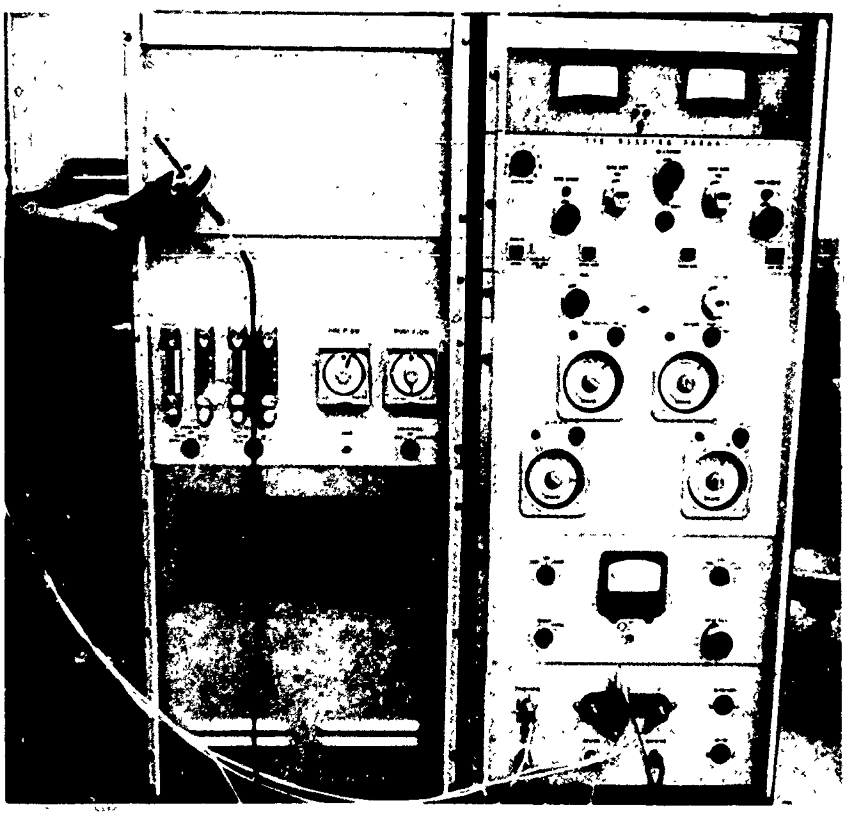

Figure 21 Automatic Tube Welder Control Panel

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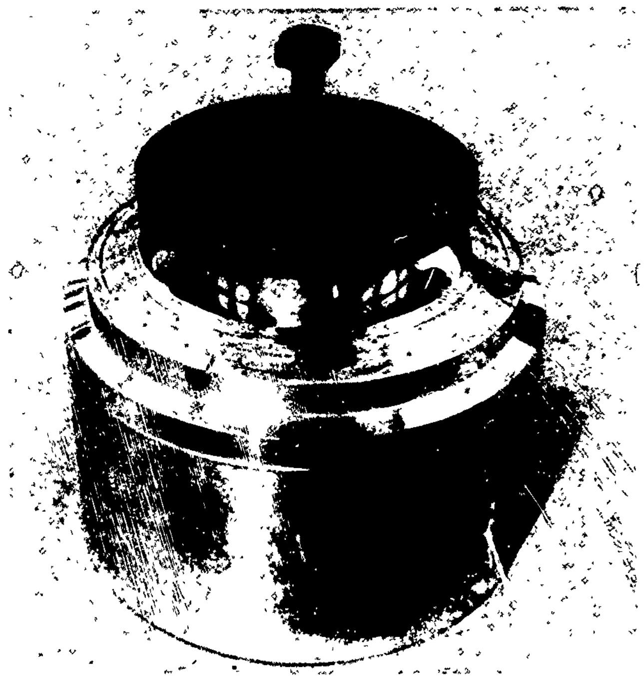

Figure 22 Fixture for Holding Dome and Access Port Fitting during Welding

Figure 23 Fixture for Holding Dome and End Fitting during Welding

SECTION IV

ACCEPTANCE TESTING

The operations relative to gas leak check, hydrostatic test, cleaning, and propellant passivation of the tanks are discussed here. After each tank was completed it was delivered to the Hazardous Materials Laboratory for performance of these tests and the operations.

1. GAS LEAK CHECK

All tanks were found acceptable when leak checked with nitrogen at 20 psig except for the 2014-T6 tanks. These tanks had minute leaks which were subsequently repaired and found acceptable. (A gas leak check was added to the original test procedure to assure that no tank had a flaw that could rupture during hydrostatic testing.)

2. HYDROSTATIC TESTING

The tanks were filled with water containing a red dye. All weld areas and joints were coated with dye check developer on exterior surfaces (Fig. 25). The presence of dye in the water and the white developer on tank exteriors was intended to assist in leak detection. Testing in the test cells was observed on closed circuit television. (Fig. 24).

Pressure cycling from zero to 130 psig was accomplished five times on each tank. No leaks were detected. All tanks were found to be acceptable.

3. CLEANING

Subsequent to hydrostatic testing all tanks were cleaned in accordance with EPS 50D100 or equivalent alternative procedures that were selected as related to the type and degree of contamination present on receipt of the tanks. Before the final tank closure was installed, detailed inspection of tank interiors was accomplished to ensure that no significant contamination was present.

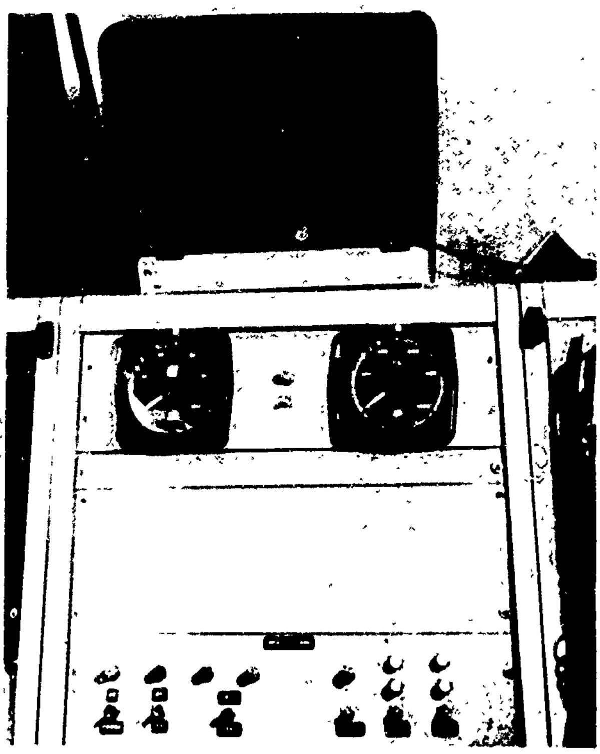

Figure 24 Control Panel and Closed Circuit Television for Low-Pressure Gas Leak Check and Hydrostatic Testing of Propellant Test Tanks.

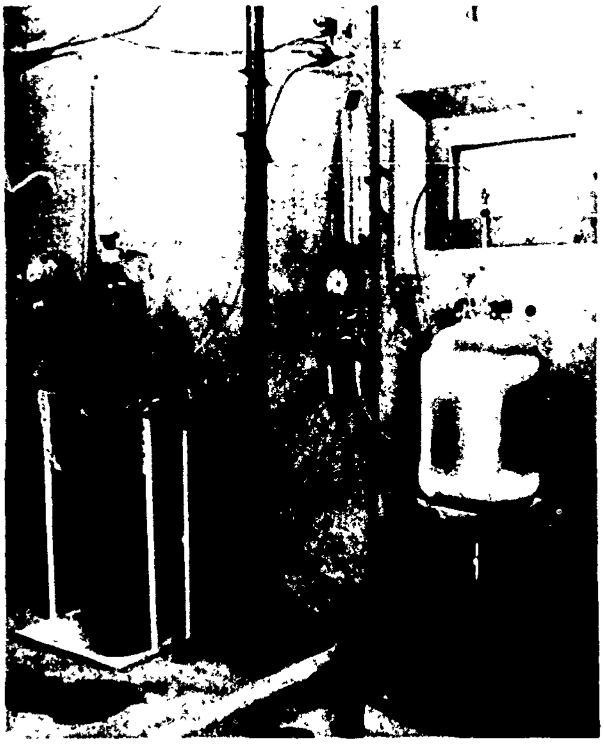

Figure 25 Tank in Blast Cell for Hydrostatic Testing (plumbing and equipment include solenoids for pressurization, safety equipment, and reservoir to assure 100% liquid in tank).

4. PROPELLANT PASSIVATION

All tanks were subjected to propellant, in a closed system to determine whether any chemical reaction would take place between propellant and tankage materials. Two passivation procedures were employed, depending on the materials used for tank construction. The procedures are described below (refer to Fig. 26 thru 29).

Stainless steel and titanium tanks were loaded with a mixture of 40% hydrazine and 60% water. The tank was then heated to 190 ± 10°F and maintained for 24 hours during which time tank pressure was monitored.

Stainless steel tank pressures rose 4 psi during the first 6 to 8 hours of heating, then stabilized. This showed that no further significant propellant decomposition occurred.

Titanium tanks showed no pressure rise in the 24-hour period.

Aluminum tanks were filled to 1/2 their volume with pure hydrazine then heated to 125 ± 10°F and maintained for 24 hours with pressure monitored during the cycle. Tanks were rotated frequently to insure that liquid contact was made for at least one hour on all tank surfaces.

No pressure rise was noted on the gage during the heat cycle. A minor amount of pressure was found to have occurred as observed at the discharge port of the vent system. This pressure was insufficient to be seen on the gage.

5. DRYING

At the termination of propellant passivation, all tanks were flushed with filtered demineralized water (10 microns) to remove residual propellant. The tank interiors were then dried to a maximum dew point of -35°F and sealed.

Figure 26 Propellant Tank Passivation Insulation Set-Up for Stainless Steel and Titanium Tanks.

Figure 27 Aluminum Propellant Tank Passivation Set-Up.

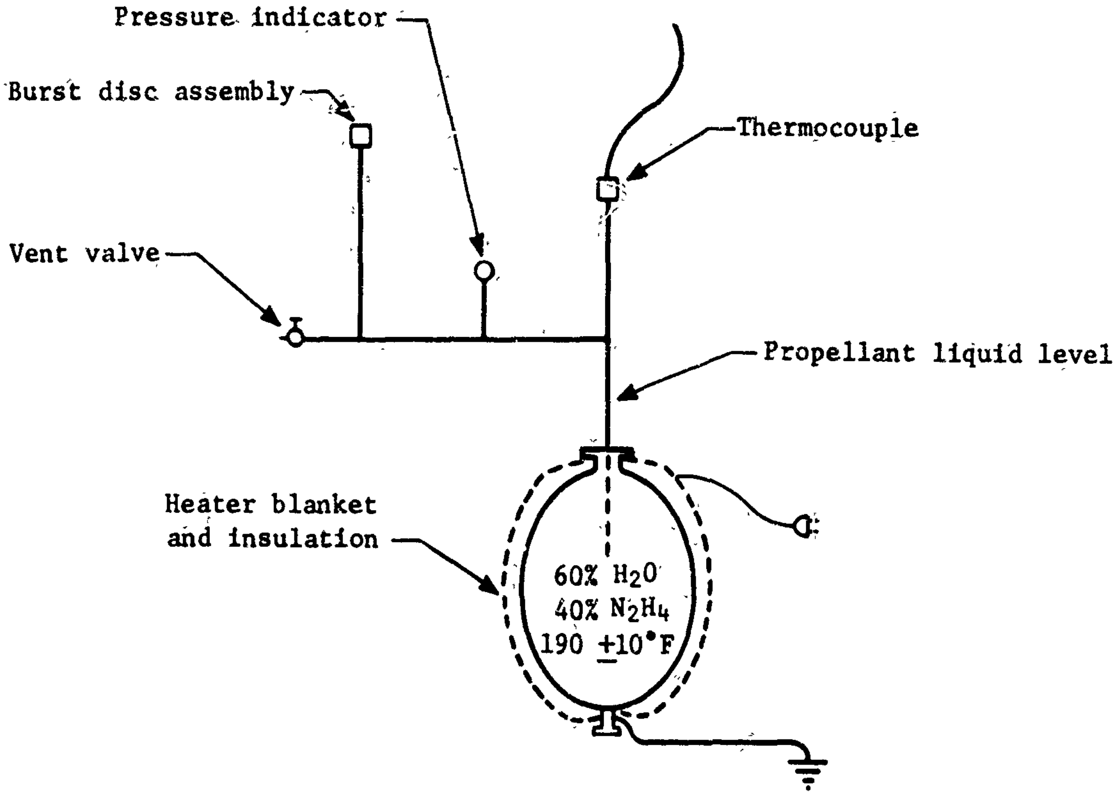

Figure 28 Schematic of System for Accelerated Propellant Compatibility and Passivation Test for Stainless Steel and Titanium Tanks.

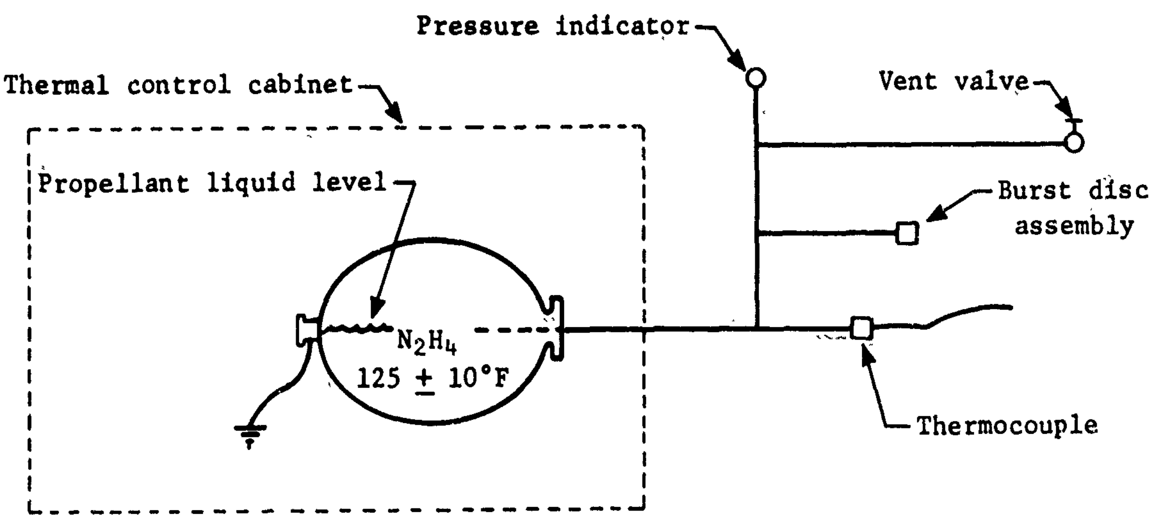

Figure 29 Schematic of System for Accelerated Propellant Compatibility and Passivation Test for Aluminum Tanks.

SECTION V

DISCUSSION AND CONCLUSIONS

1. DESIGN

The tank design was similar in most respects to the configuration employed in Contract AF04(611)-1074. The only significant changes were increase in volume (from 10 to 15 gallons) by stretching the tank length, modifying fitting configuration, and location of girth welds to facilitate welding.

The results were as follows:

1) Length change - no effect on manufacturing or inspection operations;

2) Fitting configuration - increased cost of fittings was not offset in short run production efficiency;

3) Girth weld relocation - girth weld was moved away from dome tangency point to minimize mismatch and facilitate welding. Result was satisfactory, but was offset by additional problems in explosive forming domes which required deeper draw and longer straight cylindrical sections.

2. ASSEMBLY TOOLING

Tooling designed for this contract was more sophisticated and of higher quality than that on previous similar contracts. Its additional cost was offset by its added efficiency once the fixtures had been checked out and experience gained in their operation.

3. EXPLOSIVE FORMING

While some difficulty was experienced in fabrication of domes from AM-350 corrosion-resistant steels and titanium 6Aℓ-4V, the technology level has improved markedly because:

1) This design (greater straight length and deeper draw) is considerably more difficult than the previous design;

2) Corrosion-resistant steel domes were satisfactorily formed without the use of the steel sandwich technique (expensive) required for the 1965 production;

3) Titanium domes were formed in one piece without the use of steel sandwich. Considerable difficulty was encountered, but progressive forming-stress relief cycles proved satisfactory. Previously (1965), separate dome gore segments were Marformed by the Baltimore Division of Martin Marietta Corporation;

4) Early attempts to final size preformed domes in lightweight plastic lined dies resulted in premature die failure. All tank domes furnished were made on the die illustrated in Figure 2.

4. WELDING

Acceptance testing revealed leakage in three 2014 aluminum alloy tanks. All 2014 tanks were 100% radiographed, defects located (microporosity), and repaired. No other difficulty was encountered during the course of the production effort.

5. ACCEPTANCE TESTING - CLEANING AND PASSIVATION

Particular attention was given to final processing following completion of the assembled tank. This was due in part to difficulties encountered on previous contracts in which additional cleaning was required after tanks had been received at AFRPL. In addition, the passivation tests were developmental in nature and were therefore closely controlled.

a. Cleaning. Each tank was carefully examined after final cleaning. All tanks were visibly clean and showed no evidence of stains or internal residue.

b. Passivation. The accelerated compatibility and passivation tests were completed without incident. Of particular interest, however, was a slight irridescent, stain-like discoloration appearing on the inside of an aluminum alloy tank following a pilot run passivation. This is mentioned so that AFRPL personnel do not confuse this discoloration with a lack of cleanliness if these tanks are opened before use at AFRPL.

6. ADDITION OF MS 27851-TYPE FLUID CONNECTORS

Addition of the connectors presented no unusual difficulties. The equipment illustrated in Figures 19, 20, and 21 was used. On completion of the modification, the mechanical connectors were coupled and torqued to values specified by the connector manufacturer. The tanks were then retested hydrostatically to assure joint integrity. While no difficulty was encountered with the steel or titanium connectors, the aluminum alloy seals appeared to be sensitive to movement (plumbing line movement or vibration, etc).

7. RELIABILITY AND MAINTAINABILITY

One purpose of the AFRPL Storability Program is to develop reliability and maintainability information as a part of the evaluation on completion of the current program. It is impossible at this time to base any meaningful predicted data where only short manufacturing runs of five tanks per alloy were made. It may be stated, however, that the cleaning and passivation of these tanks (the most critical point other than leakage in the storage of N_2H_4) represents the latest processing developments realized from Martin Marietta's long experience and continuing research and development in hydrazine fuels storability technology.

8. ACCEPTANCE TEST AND TRACEABILITY RECORDS

Acceptance test report information and traceability records will be included under separate letter. Tank inspection and production logs provide verification of testing witnessed by Denver AFPRO Inspectors.

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13. ABSTRACT

This report summarizes the work performed in designing, fabricating, and testing small-scale storable propellant tanks. The design incorporates full-scale missile tank features and typical weld stresses. Fabrication and test procedures are based on simulated production tooling and on actual procedures used in the manufacture of production tankage. The tank designs are based on seven different alloys. Five tanks were produced from each alloy. The alloys were: 2014-T6 aluminum alloy; 2021-T6 aluminum alloy; 2219-T-6 aluminum alloy~~s were~~; ~~2014-T6~~ 17 resistant steel; A-286 corrosion-resistant steel; AM-350 corrosion-resistant steel; and 6Al-4V titanium alloy. The tanks will be filled with N_2H_4 at the Rocket Propulsion Laboratory and stored in the RPL Storability Test facility. Test facility. Tanks will not require passivation at RPL since they have been given a special accelerated hydrazine storability test at Martin Marietta. This process includes passivation.

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
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Propellant Storability Test Tanks						
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N_2H_4 Tankage Passivation						
Explosive Formed Domes						
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